Science of the Total Environment 621 (2018) 1491–1498

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The burden of ambient temperature on years of life lost: A multi-community analysis in Hubei, China

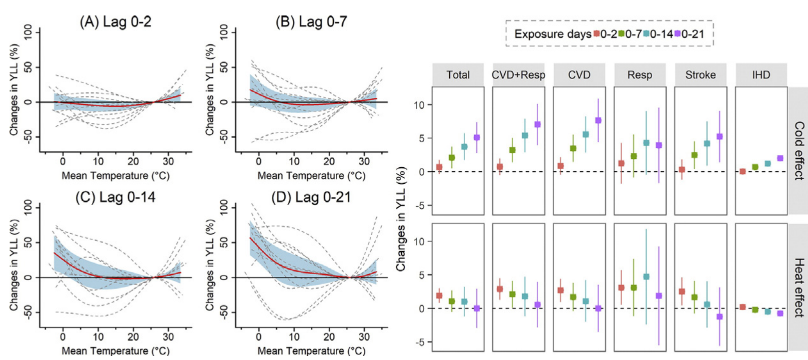
Yunquan Zhang [a], Chuanhua Yu [a,b,*], Minjin Peng [c], Lan Zhang [d]

[a] Department of Preventive Medicine, School of Health Sciences, Wuhan University, 185 Donghu Road,Wuchang District, Wuhan 430071, China
[b] Global Health Institute, Wuhan University, 8 Donghunan Road, Wuchang District, Wuhan 430072, China
[c] Department of Infection Control, Taihe Hospital, Hubei University of Medicine, Shiyan 442000, China
[d] Office of Chronic Disease, Hubei Provincial Center for Disease Control and Prevention, 6 Zhuodaoquan Road, Wuhan 430079, China

HIGHLIGHTS

- Temperature-YLL association was assessed at the provincial level in Hubei, central China.
- Cold rather than heat contributed prolongly and substantially to mortality-specific YLLs.
- Low-educated persons suffered greater burden of YLL due to extreme temperatures.
- Findings are important for better understanding of health burden due to temperature extremes in China.

GRAPHICAL ABSTRACT



Left panel: Community-specific and pooled exposure-response curves between daily mean temperature and percentage changes in YLL (%) due to non-accidental mortality at different cumulative lag days for the twelve communities across Hubei Province, China.
Right panel: Pooled cumulative heat and cold effects on mortality-specific YLLs (%) at exposure days of lag 0–2, 0–7, 0–14, and 0–21. Heat (cold) effects were presented as percentage changes in YLL associated with per 1 °C increase (decrease) from 75th (25th) percentile to 99th (1st) percentile of temperature.

ARTICLE INFO

Article history:
Received 24 June 2017
Received in revised form 7 September 2017
Accepted 9 October 2017
Available online 18 October 2017

Editor: D. Barcelo

Keywords:
Climate change
Temperature
Burden of disease
Mortality
Years of life lost

ABSTRACT

Background: Compared with death rates, years of life lost (YLL) has been widely used as a more informative indicator to quantify the burden of premature death. In the context of global climate change, existing evidence linking ambient temperatures and YLL was very scarce across the globe.
Methods: Daily mortality and meteorological data during 2009–2012 were obtained from 12 communities across Hubei Province in central China. A two-stage approach was used for statistical analysis. At the first stage, a generalized linear regression combined with distributed lag non-linear model was applied to estimate community-specific temperature-YLL associations. A second-stage multivariable meta-analysis was then conducted to pool the community-specific estimates of temperature-related effects on YLL.
Results: A pooled J- or U-shaped association was observed between ambient temperature and YLL due to different mortality categories. Heat effects occurred immediately and only persisted for several days, whereas cold effects were delayed and much longer-lasting. At the provincial level, heat effect (per 1 °C increase from 75th to 99th percentile of temperature) at lag 0–2 days and cold effect (per 1 °C decrease from 25th to 1st percentile of temperature) at lag 0–21 days was associated with an increase of 1.91% (95% CI: 0.83, 3.00) and 5.09% (2.79, 7.40) in YLL due to non-accidental deaths, respectively. Much greater effect estimates of cold than heat were also

* Corresponding author at: Department of Preventive Medicine, School of Health Sciences, Wuhan University, 185 Donghu Road,Wuchang District, Wuhan 430071, China.
E-mail address: YuCHua@whu.edu.cn (C. Yu).

https://doi.org/10.1016/j.scitotenv.2017.10.079

observed for other mortality-specific YLLs (except for respiratory mortality). Heat effects on YLL were higher for males and the youth, while cold effects were greater for females and the elderly. Additionally, relatively stronger associations between heat, cold and YLL were consistently observed in low-educated persons.

Conclusions: This multi-community study strengthened the evidence that both cold and hot temperatures were associated with increased years of life lost. Our findings may have important implications for better understanding the burden of premature death related to temperature extremes.

1. Introduction

As the greatest global threat for human health in the 21st century, climate change has a series of direct or indirect impacts on the vast majority of the world's population (Anthony et al., 2009; Huang et al., 2013). Over the past decade, temperature-related health assessment has gotten rapidly increasing interest in the field of environmental epidemiology (Carlton et al., 2016; Phung et al., 2016b; Wang et al., 2017; Ye et al., 2012; Zhang et al., 2017d; Zhao et al., 2017). As well documented in numerous previous epidemiological studies, temperature and its variability have been linked with a variety of health outcomes (e.g., morbidity and mortality) (Basu, 2009; Bunker et al., 2016; Cheng et al., 2014; Guo et al., 2014; Guo et al., 2016; Kravchenko et al., 2013; Vicedo-Cabrera et al., 2016). These continually strengthened and evidence-based findings would have great implications for public decision-making and resource allocation, thus help developing early warning systems for prevention and intervention in response to climate change.

A U-, J-, or V-shaped temperature-mortality association has been comprehensively observed worldwide using time-stratified case-crossover or time series study designs (Gasparrini et al., 2015b; Guo et al., 2011; Guo et al., 2014; Tian et al., 2012; Zhang et al., 2017b). In comparison to younger persons, the elderly were more widely identified to be more vulnerable to the mortality impacts of temperature extremes (Bunker et al., 2016; Yu et al., 2012). However, these studies only took the daily death counts into consideration, and failed to account for the differences in ages at death, apart from broad age stratification (Chen et al., 2017; Guo et al., 2013a; Lu et al., 2015). As an alternative measure for premature death, years of life lost (YLL) is an estimate of the health gap in life years between the actual death age and population-averaged life expectancy (Gardner and Sanborn, 1990), and has been widely applied to evaluate the global, regional, and national mortality burden for various causes of death in the Global Burden of Disease Study 2013 & 2015 (Naghavi et al., 2015; Wang et al., 2016). Given that dying at a younger age produces greater burden from a public health perspective (He et al., 2016; Yang et al., 2015a), YLL gives more weight to deaths occurring among younger people in line with the life expectancy at death, thus argued as a more informative and accurate estimate for quantifying premature deaths than the number of deaths (Guo et al., 2013a; He et al., 2016; Yang et al., 2015a; Zeng et al., 2017; Zhang et al., 2017a).

In very recent years, studies conducted in several metropolises including Guangzhou (Yang et al., 2015a), Chongqing (J Li et al. 2016), Ningbo (G Li et al. 2017), and Harbin (YH Li et al. 2017) in China, Brisbane (Huang et al., 2012a; Huang et al., 2012b), Nairobi (Egondi et al., 2015), and 14 European cities (Baccini et al., 2013) have begun to investigate the health burden on YLL associated with ambient temperatures, cold spells, and heat waves. To date, however, the evidence linking temperature and YLL has been still very sparse, mainly because of lacking individual data needed for YLL calculation (He et al., 2016). Furthermore, the effects of both low and high temperatures on YLL may also vary substantially across countries/regions and even differentiate from city to city due to the great differences in the climate characteristics and long-term acclimation to local climate (Gasparrini et al., 2015b; Guo et al., 2014). Therefore, more epidemiologic studies using YLL as the health outcome are needed across the globe to better understand the temperature-related burden on premature death.

In the present study, we conducted an observational multi-community study in Hubei Province, central China, and aimed to examine the relationships between temperature and YLL due to different mortality categories at the provincial level. Stratified analyses by gender, age, and education level were further performed, so as to identify whether there existed some potential differences in temperature-related effects on YLL between subpopulations.

2. Materials and methods

2.1. Study area and population

Located in the middle reaches of the Yangzi River, Hubei Province was home to more than 58 million inhabitants according to the 2010 Chinese Census, with an area of 185.9 thousands km^2. Twelve communities including 6 urban districts (i.e., Jiang'an, Qiaokou, Huangshigang, Zhangwan, Maojian, and Wujiagang) and 6 rural/countryside communities (i.e., Wufeng, Macheng, Gucheng, Yingcheng, Yunmeng, and Tianmen), were included in the present study for the provincially representative sample based on the National Disease Surveillance Points (DSPs) System of China. Further detailed information including locations could be found in our previous publication (Zhang et al., 2017c). The 12 selected communities had a total of about 6.7 million permanent residents in 2010, which accounted for 11.6% of the total population in Hubei Province.

2.2. Data collection

Community-specific daily mortality data during 2009–2012 were obtained from the Hubei Provincial Center for Disease Control and Prevention. Causes of death were coded according to the Tenth Revision of the International Classification of Diseases (ICD-10), and non-accidental (A00-R99), cardiorespiratory (I00–I99 and J00–J99), cardiovascular (I00–I99), respiratory (J00–J99), stroke (I60–I69), and ischemic heart disease (IHD: I20–I25) mortality were identified and examined in the present study. Daily non-accidental death cases were further divided into several subgroups stratified by gender, age (0–74 years, 75+ years), and education level (primary school or lower: 0–6 years, secondary or higher: 7+ years).

For the same period (2009–2012), community-specific daily meteorology data including maximum, mean, and minimum temperature and mean relative humidity were obtained from the China Meteorological Data Network (http://data.cma.cn), which was launched by the China Meteorological Administration and provides a publicly available data sharing service.

2.3. YLL calculation

The Chinese national life table for the year 2012 (Table S1) was first obtained from Global Health Observatory (GHO) data on WHO website (http://www.who.int/gho/countries/chn/en/), which estimated age-specific life expectancy for both sexes from 2000 to 2015 at the national level. According to previous studies (Guo et al., 2013a; He et al., 2016; Yang et al., 2015a), YLL for each death was then calculated by matching age and sex to the reference life table. Community-specific daily YLLs could be consequently obtained by summing the YLL of all death cases

on that day. Daily total YLLs were further divided into different mortality types and stratified by gender, age, and education level described above (Zhang et al., 2017e).

2.4. Data analysis

In the present study, a two-stage data analysis (Gasparrini et al., 2015b; Guo et al., 2016; Yang et al., 2015b; Yang et al., 2016b) was conducted to assess temperature-YLL association. Community-specific temperature effects on daily YLL were estimated at the first stage, and a second-stage meta-analysis was then used to obtain the pooled estimates at the provincial level.

At the first stage, we applied a standard time-series generalized linear model (GLM) combined with distributed lag non-linear model (Gasparrini et al., 2010) (DLNM) to examine community-specific non-linear and lag effects of temperature on YLL. Since daily YLLs generally followed a normal distribution (Guo et al., 2013a; He et al., 2016; Huang et al., 2012b) (Fig. S1), we specified a distribution family of Gaussian for daily YLLs in the GLM. To control for the heterogeneity in daily YLLs across communities caused by various population sizes and basal mortality rates, daily YLL data for each community were transformed into percentage deviation (%) variables. Specifically, we first subtracted the daily mean YLL value during the study period from the observed YLL values on a specific day, divided the residuals by the mean YLL for each community, and finally multiplied the outcomes by 100. The calculating formula for percentage deviation of daily YLL can be also expressed as:

$$\mathrm{PYLL}_{n,i} = \left(\mathrm{YLL}_{n,i} - \overline{\mathrm{YLL}_n}\right)/\overline{\mathrm{YLL}_n} \times 100$$

where $\mathrm{PYLL}_{n,i}$ indicates percentage deviation (%) of YLL for community n ($n = 1, 2, ..., 12$) at calendar day i ($i = 1, 2, ..., 1461$), and $\mathrm{YLL}_{n,i}$ represents the originally observed daily YLL; $\overline{\mathrm{YLL}_n}$ is the average value of daily YLL for community n during the whole study period.

This so called mean-centered approach has been also used in previous panel studies assessing air pollution and temperature-related impacts on health (Penttinen et al., 2001; Wu et al., 2014; Wu et al., 2013). Given the substantial variation in the absolute values of YLLs across communities, the above-described transformation made it feasible to pool the community-specific nonlinear temperature-YLL relationships at a comparable relative scale (i.e., percentage deviation). Community-specific GLM was given as follows:

$$\mathrm{E}(Y_i) = \alpha + \beta Temp_{t,l} + ns(Time, df = 7 \times 4) + ns(Humdity_i, df = 3) + \gamma DOW_i + \delta Holiday_i$$

where Y_i was the percentage deviation (%) variables of observed daily YLLs (above-calculated PYLL) at calendar day i ($i = 1, 2, ..., 1461$); α was the intercept; $\mathrm{Temp}_{t,l}$ was the cross-basis matrix of mean temperature (t) and lag pattern (l) produced by DLNM. In this cross-basis matrix, the exposure-response association was modelled with a natural cubic spline (ns) with three internal knots placed at the 10th, 50th, and 90th percentiles of community-specific temperature distributions, and the lag-response association was modelled with a ns function and three internal knots placed at equally-spaced values in the log scale (Gasparrini et al., 2015b; Ma et al., 2015). The maximum lag up to 21 days was selected for temperature according to previous studies (Gasparrini et al., 2015b; Guo et al., 2014). 7 degrees of freedom (df) per year was chosen to control for long-term trend and seasonality (Zhang et al., 2017b), and a ns function with 3 df was used to eliminate the confounding effect of relative humidity. Additionally, day of the week (DOW) and public holiday (Holiday) were adjusted for in the GLM as indicator variables (Zhang et al., 2016).

At the second stage, a multivariate meta-analysis (Gasparrini et al., 2012) was employed to pool the community-specific estimates so as to obtain the temperature–YLL relationship at the provincial level. Compared with the traditional meta-analysis method, multivariate meta-analytical models could provide much greater flexibility to capture the multi-parameterized non-linear exposure-response associations from multiple sites (Gasparrini et al., 2012). To pool the temperature effects on YLL, we reduced the bi-dimensional exposure-lag-response association to one-dimensional cumulative exposure-response curves for different days of lag (e.g., 0–2, 0–7, 0–14, and 0–21). This parameter-reduction step used in this methodology preserved the complexity of the estimated dependency, and could thus avoid unnecessary simplification (Gasparrini et al., 2015b).

To illustrate the effect estimates of temperatures on YLL, we calculated the percentage change of YLL comparing a percentile relative to a reference percentile of temperature, and extracted the estimates of average percentage change in YLL per 1 °C temperature change over this range (Yang et al., 2015a). Cold effects were then expressed as the average percentage change in YLL associated with a 1-°C decrease from the 25th percentile to 1st percentile of temperature, and heat effects were expressed as the average percentage change in YLL associated with a 1-°C increase from the 75th percentile to 99th percentile of temperature. To further demonstrate temperature-related health impacts, we additionally included the results for temperature-mortality associations by replacing PYLL with death counts using a quasi-Poisson regression (Zhang et al., 2017b). We also conducted cause-specific analyses for different mortality types and subgroup analyses stratified by gender, age group, and education level. To check the robustness of the results, several sensitivity analyses were performed by changing df (5–9 per year) in the smoothness of time and df (4–6) of natural cubic spline for humidity.

All the analyses were performed with R software (version 3.3.2, R Development Core Team 2016). The first-stage community-specific temperature-YLL associations were obtained using the package “dlnm”, and the second-stage multivariable meta-analysis was conducted using the package “mvmeta”. Two-sided statistical tests were conducted, and effects of $p < 0.05$ were considered statistically significant.

3. Results

3.1. Data description

Table 1 gives the community-specific descriptive statistics on population sizes, total included non-accidental deaths, daily YLLs due to non-accidental mortality, and annual mean temperature and relative humidity. The selected communities covered a population of 6.7 million and a total of 146,676 non-accidental deaths were observed during the study period. Daily YLLs varied greatly across communities, which was mainly due to the huge heterogeneity in population sizes. A daily average of 136.7 YLL was induced by 9.1 non-accidental deaths, with the lowest in Wujiagang (33.9 years) and the highest in Tianmen (324.3 years). Generally, the study locations demonstrated similar climate characteristics, with the annual mean temperature of 16.6 °C (from 14.7 to 17.4) and mean relative humidity of 74.7% (from 67.6 to 77.7).

3.2. Contour plots and lag patterns

Fig. S2 shows the community-specific contour plots of temperature-YLL relationships along different lag days. Generally, short-term exposures to both low and high temperatures were associated with increased daily YLL, while some distinct differences were also observed in the effect estimates and specific lag patterns. Heat effects, for instance, appeared acutely but persisted shortly, and showed zero effects at longer lags in some communities (e.g., Jiang'an, Qiaokou, and Tianmen); however, other communities also revealed longer-lasting impact (Wujiagang), some displacement (e.g., Huangshigang and Yingcheng), and null associations (e.g., Wufeng) in the effects of high temperatures. Pooled analyses indicated an acute heat effect but a longer-lasting cold effect at the provincial level (Fig. 1).

Table 1
Descriptive statistics of community-specific population sizes, included non-accidental deaths, daily YLLs due to non-accidental mortality, annual mean temperature, and relative humidity for the twelve communities during 2009–2012.

Community	Population size (million)	Non-accidental death (count)	Daily YLLs due to non-accidental mortality (years)						Mean temperature (°C)	Relative humidity (%)
			Mean	SD	P_{25}	P_{50}	P_{75}	Range		
Urban										
Jiang'an	0.68	16,895	155.6	63.0	109.8	147.1	195.0	6.6–396.6	16.8	76.6
Qiaokou	0.54	14,362	132.3	57.4	90.9	124.3	169.6	12.3–339.6	16.8	76.6
Huangshigang	0.17	3496	34.5	30.0	11.5	28.0	48.7	0–254.5	17.4	77.1
Zhangwan and Maojian	0.39	7805	91.7	55.8	50.6	82.3	120.5	0–319.2	15.4	74.8
Wujiagang	0.15	3382	33.9	28.4	12.3	27.2	47.5	0–252.8	17.2	74.4
Rural										
Wufeng	0.21	4475	43.5	33.4	18.5	36.4	61.3	0–206.1	14.7	76.2
Macheng	1.18	24,980	289.4	132.8	196.7	273.5	363.6	0–1123.1	17.1	67.6
Gucheng	0.54	12,899	140.5	75.8	85.4	130.5	180.5	0–571.0	16.2	73.2
Yingcheng	0.64	13,496	130.1	58.9	88.4	124.1	165.1	0–418.9	16.5	76.6
Yunmeng	0.56	12,427	127.9	66.3	81.0	120.2	164.1	0–529.6	16.5	76.6
Tianmen	1.63	32,459	324.3	114.9	243.9	315.0	394.6	28.0–946.3	17.1	72.5
Overall	6.70	146,676	136.7	116.1	49.8	108.9	186.8	0–1123.1	16.6	74.7

3.3. Exposure-response associations

Fig. 2 describes community-specific and pooled exposure-response curves between daily temperature and percentage change in YLL (%) due to non-accidental mortality at different cumulative lag days. There existed some heterogeneity in temperature-YLL relationships across communities, as demonstrated in Fig. S2. The pooled effect of high temperatures was acute (A) but insignificant at longer cumulative lag days (B, C, and D), whereas low temperatures showed little impact at lag 0–2 (A) but prolonged significant effects (C and D) on increased YLL. Generally comparable pooled patterns were also observed in temperature-related effects on YLLs caused by other mortality categories (Fig. S3). The minimum YLL temperature along lag 0–21 days was 25.9 °C, 19.3 °C, 22.0 °C, and 14.8 °C for non-accidental, cardiorespiratory, cardiovascular, and respiratory mortality, respectively. Also, very similar associations of temperature with mortality risk were observed at different cumulative lag days (Fig. S4).

Fig. 3 & Fig. S5 further illustrates the pooled cumulative cold and heat effects on mortality-specific and subpopulation YLLs at days of lag 0–2, 0–7, 0–14, and 0–21, which were presented as percentage changes in YLL associated with a 1-°C decrease/increase for cold and hot temperatures, respectively. Based on the consistencies in the effect patterns of low or high temperatures on daily YLL, exposure days of lag 0–2 and lag 0–21 were thus finally used to report the effects related to heat and cold, respectively.

3.4. Heat and cold effects on YLL and mortality due to cause-specific categories

Table 2 summarizes the pooled heat effects at lag 0–2 days and cold effects at lag 0–21 days on daily percentage changes in YLL due to different mortality types. Both hot and cold temperatures showed significant effects on mortality-specific YLLs, except for cold effect on YLL due to respiratory mortality. Heat effects peaked for respiratory mortality with an increase of 3.11% (95% CI: 0.53, 5.70), while cold effects peaked for cardiovascular mortality with an increase of 7.65% (4.40, 10.90). For non-accidental mortality, heat effect and cold effect were associated with an increase of 1.91% (0.83, 3.00) and 5.09% (2.79, 7.40) in YLL, respectively. Cold effects were generally much greater than heat effects, whereas comparable effect estimates were observed for the cold and heat effects on YLL related to respiratory mortality. For example, heat effects induced an increase of 2.88% (1.28, 4.48) and 2.53% (0.43, 4.63) in YLL for cardiorespiratory and stroke mortality respectively, and the corresponding estimates for cold effects were 7.05% (3.98, 10.11) and 5.26%

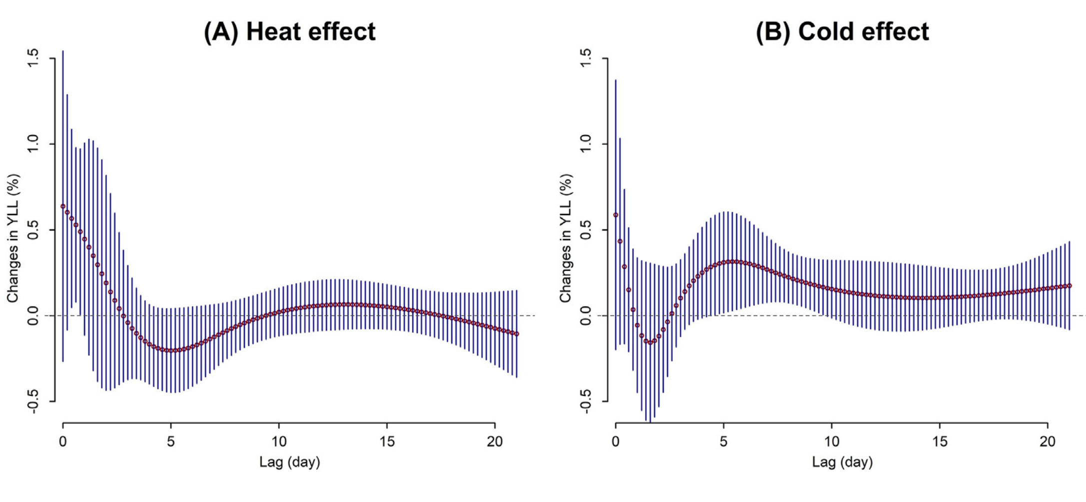


Fig. 1. Lag patterns of pooled heat effect (A) and cold effect (B) on YLL due to non-accidental mortality for the selected communities across Hubei Province, China. Heat effect was presented as percentage changes in YLL associated with per 1 °C increase from 75th percentile to 99th percentile of temperature. Cold effect was presented as percentage changes in YLL associated with per 1 °C decrease from 25th percentile to 1st percentile of temperature.

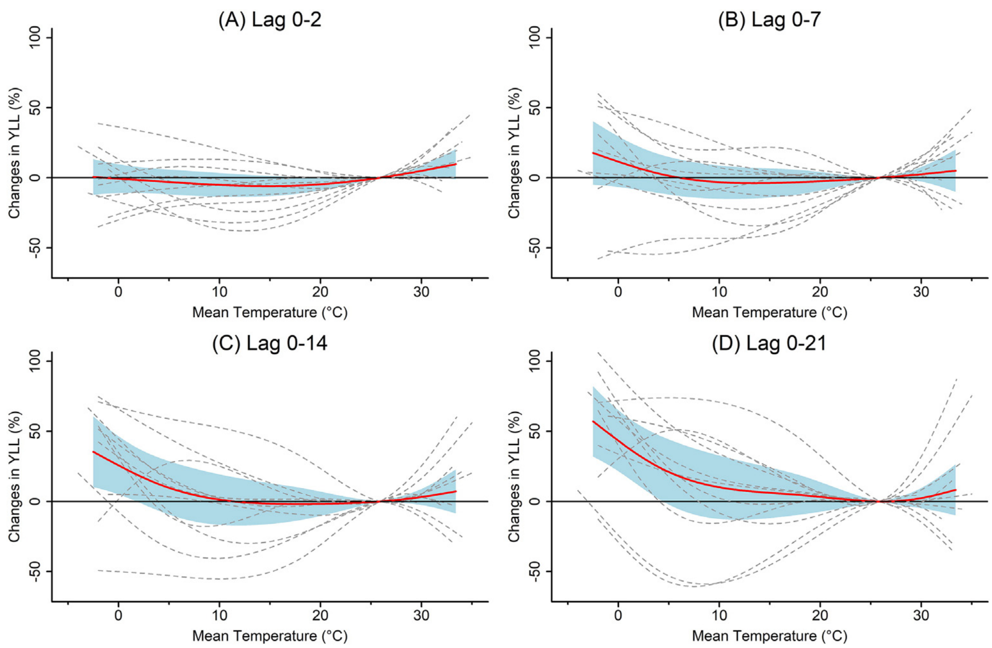


Fig. 2. Community-specific and pooled exposure-response curves between daily mean temperature and percentage changes in YLL (%) due to non-accidental mortality at different cumulative lag days for the twelve communities across Hubei Province, China. The continuous bold red lines are the pooled curves and the blue areas represent the 95% confidential intervals, whereas the long-dashed grey lines represent the community-specific dose-response relationships. The reference temperature was 25.9 °C.

(1.43, 9.09). Comparably, we identified similar heat-cold differences in the effect estimates when assessing mortality risk associated with daily mean temperature.

3.5. Heat and cold effects on YLL for subgroups stratified by individual characteristics

Table 3 calculates the pooled heat effects at lag 0–2 days and cold effects at lag 0–21 days on percentage changes in YLL for subgroups stratified by gender, age, and education level. Heat effects on YLL were higher for males and persons aged 0–74 years, while cold effects were greater for females and the elderly aged 75 years and older. Relatively stronger associations between heat, cold and YLL were consistently observed in persons with low education level.

4. Discussion

By using a unified analytical approach for each community and then performing a pooled analysis, we linked significant increases in YLL with both low and high mean temperature in Hubei Province, characterized

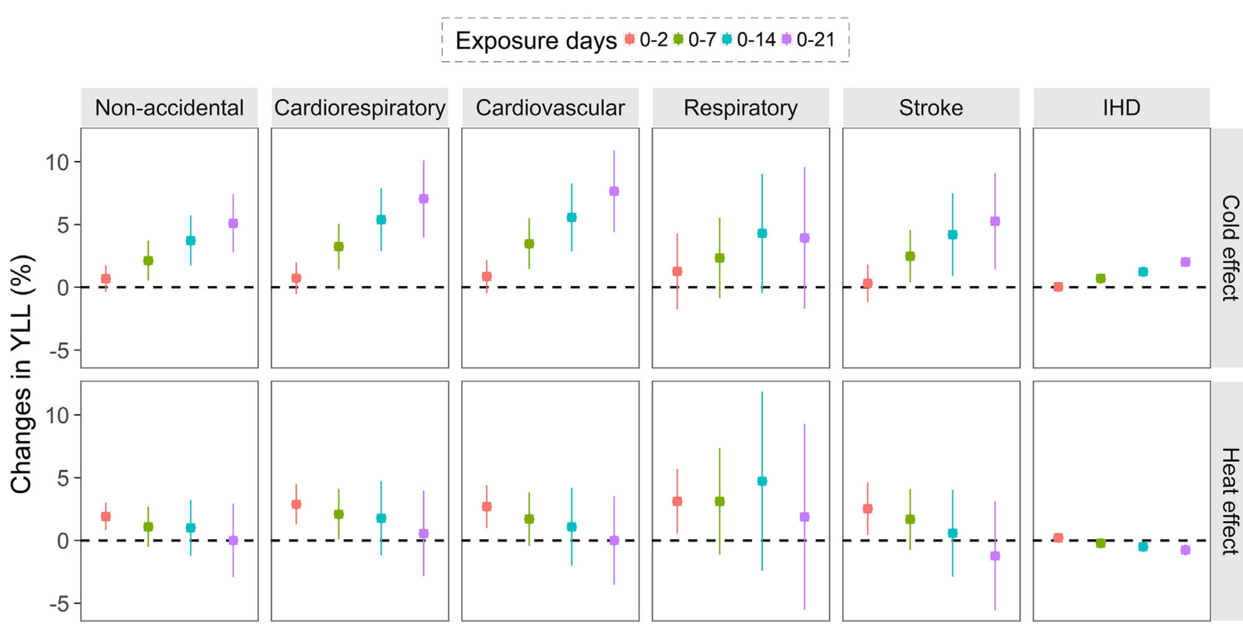


Fig. 3. Pooled cumulative cold and heat effects on mortality-specific YLLs (%) at exposure days of lag 0–2, 0–7, 0–14, and 0–21. Cold effects were expressed as the average percentage changes in YLL associated with a 1-°C decrease from the 25th percentile to 1st percentile of temperature, and heat effects were expressed as the average percentage changes in YLL associated with a 1-°C increase from the 75th percentile to 99th percentile of temperature.

Table 2
Pooled heat effects at lag 0–2 days and cold effects at lag 0–21 days on percentage changes of YLL and mortality due to cause-specific categories.

Cause-specific outcomes	Heat effect (lag 0–2)	Cold effect (lag 0–21)
YLL		
Non-accidental	1.91 (0.83, 3.00)	5.09 (2.79, 7.40)
Cardiorespiratory	2.88 (1.28, 4.48)	7.05 (3.98, 10.11)
Cardiovascular	2.70 (0.98, 4.41)	7.65 (4.40, 10.90)
Respiratory	3.11 (0.53, 5.70)	3.93 (−1.71, 9.56)
Stroke	2.53 (0.43, 4.63)	5.26 (1.43, 9.09)
IHD	0.21 (0.04, 0.38)	2.01 (1.66, 2.35)
Mortality		
Non-accidental	2.91 (1.69, 4.14)	5.65 (3.07, 8.29)
Cardiorespiratory	3.95 (2.04, 5.90)	6.94 (4.04, 9.91)
Cardiovascular	3.80 (1.53, 6.12)	6.84 (3.90, 9.87)
Respiratory	4.80 (2.05, 7.62)	6.31 (1.71, 11.13)
Stroke	3.11 (1.06, 5.20)	5.57 (1.91, 9.35)
IHD	3.06 (−0.26, 6.48)	8.27 (3.16, 13.64)

with a humid subtropical climate. In the context of global climate change, our study adds strong evidence that extreme temperatures also have a great impact on years of life lost. This would contribute to better understanding of health burden related to climate change, and provide important implications to help developing preventive and control strategies for public health authorities.

Compared with mortality and morbidity, YLL was an emerging health outcome used in time-series analysis (Huang et al., 2012b) and has been applied to assess the effects of air pollution in several recent studies (Chen et al., 2017; Guo et al., 2013a; Yang et al., 2016a; Zeng et al., 2017). In the field of environmental epidemiology, increasing evidence has suggested that YLL could be regarded as an important supplementary index for daily deaths, as it provided more accurate estimation and informative understanding in the burden of premature death associated with air pollution and temperature extremes (Guo et al., 2013a; Huang et al., 2012b). In this sense, future investigations should focus on more sophisticated designs to further illustrate the close-to-reality relations between YLL and environmental exposures.

In this study, we identified a pooled J- or U-shaped temperature-YLL relationship, indicating that both low and/or high temperatures were associated with increased years of life lost. This finding was consistent with most of other available epidemic evidence (Egondi et al., 2015; Huang et al., 2012b; Yang et al., 2015a), despite focusing on climatically and geographically different locations. As demonstrated in several single-city studies, results expressed as absolute changes in YLL associated with temperature (Huang et al., 2012b; Yang et al., 2015a) or air pollution (Lu et al., 2015; Zeng et al., 2017) may vary greatly by studies, which was mainly due to the great differences in the baseline deaths occurring daily among different study populations. Distinct from previous studies, mean-centered values in the percentage scale instead of the original daily YLLs were introduced into the GLM regression analysis as the independent variable. Such a transformation in daily YLL series for each community could facilitate the comparison in the effects of ambient temperatures on YLL between studies, thus making it possible to pool the exposure-response relationships from multiple locations using a multivariable meta-analysis. Further, this centralized transformation for community-specific YLL would be more applicable and appropriate to assess the vulnerability for different mortality categories and subpopulations.

Table 3
Pooled heat effects at lag 0–2 days and cold effects at lag 0–21 days on percentage changes of YLL (%) for subgroups stratified by gender, age, and education level.

Subgroups	Heat effect (lag 0–2)	Cold effect (lag 0–21)
Gender		
Male	1.98 (0.69, 3.27)	4.62 (1.82, 7.42)
Female	1.65 (−0.09, 3.40)	5.51 (2.24, 8.79)
Age (years)		
0–74	1.12 (0.54, 1.70)	1.02 (−0.13, 2.18)
75+	0.22 (0.05, 0.39)	1.20 (0.86, 1.54)
Education level		
Primary school or lower	2.33 (0.52, 4.13)	5.11 (1.04, 9.18)
Secondary or higher	2.11 (0.62, 3.60)	4.53 (1.66, 7.40)

In accordance with a previous Chinese investigation (Yang et al., 2015a), significant heat effects on YLL appeared immediately but weakened quickly, as shown in Fig. 1. The observed weak vulnerability to high temperatures could be possibly explained by climate adaptation. Also, some changes in human behaviors including increased use of air conditioning and improved building design, may contribute to offsetting the potential adverse impacts of hot temperatures to some extent (Gasparrini et al., 2015a; Huang et al., 2012b). Given the acute but short heat-related effects on YLL, only timely preventive actions would help to reduce the health effects of hot temperatures in summer from the standpoint of public health (Guo et al., 2014). Recently, low temperatures were considered to account for the most majority of daily premature deaths attributable to non-optimal temperatures in a multi-country observational study (Gasparrini et al., 2015b) and two Chinese multi-city investigations (Yang et al., 2015b; Yang et al., 2016b). Regardless of more frequent low-temperature days, our analyses confirmed such stronger cold effects than heat effects on the burden of YLL, though expressed as percentage changes associated with per 1 °C fluctuation in daily temperature. Notably, under a global warming scenario, this study confirmed that cold weather should be still listed as an important public health problem, even in subtropical areas with hot summers (Huang et al., 2012b; Ma et al., 2015). Furthermore, protection against cold temperatures in winter should persist for a number of days after the cold exposure due to its longer-lasting impacts on mortality (Zhang et al., 2017b; Zhou et al., 2014) and YLL (Huang et al., 2012b; Yang et al., 2015a).

In this study, both extremely low and high temperature increased the mortality risks from cause-specific categories, the finding of which was in line with other multi-city or multi-community investigations (Anderson and Bell, 2009; Ban et al., 2017; Ma et al., 2014). Despite diversified climate characteristics, cardiovascular and respiratory mortality were generally found to be more strongly influenced by ambient temperature extremes. Our results estimated from both YLL and death counts further strengthened this finding. This was because that cold environment and heat stress may be more biologically associated with human cardiopulmonary system through the adverse effects on respiratory health (e.g., impaired lung function and respiratory symptoms) (Q Li et al. 2016; Li et al., 2014) and physiological changes (e.g., heart rates, blood pressure, and cholesterol levels) (Ma et al., 2014; Yang et al., 2015b). Additionally, strong associations of ambient temperature with short-term deaths from IHD and stroke were reported in some other subtropical locations (Chen et al., 2013; Guo et al., 2013b; Yang et al., 2016b). To date, however, little YLL-based evidence has focused on different subtypes of cardiorespiratory mortality, which may have largely hampered our further understanding of the potential subtle differences in temperature effects on cause-specific health endpoints.

A number of prior epidemiologic studies (Huang et al., 2015; Xie et al., 2013) have shown that gender may be a potential effect modifier when evaluating temperature-mortality relationship, in spite of less consistent evidence observed in different investigations. Previously in Brisbane, Australia, Huang et al. identified females as the susceptible groups to the impact of both low and high temperature on YLL (Huang et al., 2012b). Our pooled results showed higher heat effects among males than females, with the opposite trend for cold effects. This inconsistency between genders in the estimates of YLL due to extreme temperatures was also observed in Yang et al.'s study conducted in Guangzhou, China (Yang et al., 2015a), and could be generally attributable to biological differences and socioeconomic factors (Yang et al., 2015a; Zhang et al., 2017b; Zhou et al., 2014). More conclusively, due

to poor physiologic function, reduced organism immunity ability, and some certain pre-existing chronic diseases, the elderly were usually reported to be of high vulnerability to temperature extremes in terms of morbidity and mortality (Chen et al., 2016; Huang et al., 2015; Phung et al., 2016a; Zhou et al., 2014). However, ambient temperatures may have a different impact pattern on YLL among younger and elder groups, since life expectancy at death and the number of death are both taken into consideration when using YLL as the health outcome. For instance, Yang et al. linked greater YLL impacts with cold and hot temperatures among the youth (Yang et al., 2015a), while our results showed stronger cold effects in the elderly but stronger heat effects in the youth. This inconsistent vulnerability was also demonstrated in prior studies assessing the effects of air pollution on YLL (Guo et al., 2013a; He et al., 2016). Further well-designed studies should be conducted to understand the discrepancy in pursuit of the optimization of health resources allocation, and policy-makers should also pay appropriate attention to the risk management as well as preventive actions for the youth in coping with extreme weather conditions (Yang et al., 2015a). Education level is usually regarded as an important index reflecting one's overall socioeconomic status. Low-educated persons are more likely to have poorer living conditions and health status, riskier behavior patterns, and more limited access to health care (Chen et al., 2016; Huang et al., 2015; O'Neill et al., 2003). In accordance with most previous temperature-mortality studies (Chen et al., 2016; O'Neill et al., 2003; Yang et al., 2012), persons with low education attainment were also found to be more susceptible to both cold- and heat-associated effects on YLL than those with higher education level.

Several limitations of this study should be mentioned. First, ambient air pollutants (e.g., particulate matter, SO_2, and NO_2) (Guo et al., 2013a; Lin et al., 2016) were not included as potential covariates in our analysis due to data unavailability. However, our main findings would not be substantially affected, because the effects of ambient temperatures showed little changes with and without air pollution adjusted for in the analytical models according to previous studies (Anderson and Bell, 2009; Chen et al., 2015; Xie et al., 2013). Second, community-specific temperature exposures of this study were obtained from only one ground-based automatic monitoring station. Such exposure assessment couldn't fully capture the spatio-variability in ambient temperature and may introduce some inevitable measurement errors (Tian et al., 2012; Zhang et al., 2016). Additionally, daily number of deaths due to some mortality categories (e.g., respiratory mortality) was relatively small in some communities included in the present study, which may have limited our ability to establish a tenuous temperature-YLL association for specific communities, but wouldn't change our pooled effect estimates greatly at the provincial level.

5. Conclusions

This multi-community study strengthened the evidence that both cold and hot temperatures were associated with increased years of life lost in Hubei Province, China. Some potential differences in vulnerability were also observed in subpopulations stratified by gender, age, and education level. Our findings may have important implications to better understand the burden of premature death related to temperature extremes. Continuous contributions should be made worldwide to further help developing preventive and control strategies for public health authorities in response to global climate change.

Acknowledgments

The study was supported by the National Natural Science Foundation of China (Grant No. 81773552 & 81273179), and the Chinese NSFC International Cooperation and Exchange Program (Grant No. 71661167007). We appreciated the anonymous reviewers very much, whose insightful comments and suggestions contributed a lot to improving the quality of our manuscript.

Author contributions

Yunquan Zhang and Chuanhua Yu conceived and designed the experiments; Lan Zhang, Yunquan Zhang, and Minjin Peng collected the data; Yunquan Zhang cleaned the data, performed the statistical analysis, and drafted the manuscript; Chuanhua Yu revised the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

The authors declare they have no competing financial interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2017.10.079.

References

Anderson, B.G., Bell, M.L., 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology 20, 205–213.
Anthony, C., Mustafa, A., Adriana, A., Sarah, B., Sarah, B., Richard, B., et al., 2009. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet 373, 1693–1733.
Baccini, M., Kosatsky, T., Biggeri, A., 2013. Impact of summer heat on urban population mortality in Europe during the 1990s: an evaluation of years of life lost adjusted for harvesting. PLoS One 8, e69638.
Ban, J., Xu, D., He, M.Z., Sun, Q., Chen, C., Wang, W., et al., 2017. The effect of high temperature on cause-specific mortality: a multi-county analysis in China. Environ. Int. 106, 19–26.
Basu, R., 2009. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environ. Health 8, 40.
Bunker, A., Wildenhain, J., Vandenbergh, A., Henschke, N., Rocklov, J., Hajat, S., et al., 2016. Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence. EBioMedicine 6, 258–268.
Carlton, E.J., Woster, A.P., DeWitt, P., Goldstein, R.S., Levy, K.A., 2016. Systematic review and meta-analysis of ambient temperature and diarrhoeal diseases. Int. J. Epidemiol. 45, 117–130.
Chen, R.J., Wang, C.C., Meng, X., Chen, H.L., Thach, T.Q., Wong, C.M., et al., 2013. Both low and high temperature may increase the risk of stroke mortality. Neurology 81, 1064–1070.
Chen, K., Bi, J., Chen, J., Chen, X., Huang, L., Zhou, L., 2015. Influence of heat wave definitions to the added effect of heat waves on daily mortality in Nanjing, China. Sci. Total Environ. 506-507, 18–25.
Chen, K., Zhou, L., Chen, X., Ma, Z., Liu, Y., Huang, L., et al., 2016. Urbanization level and vulnerability to heat-related mortality in Jiangsu Province, China. Environ. Health Perspect. 124, 1863–1869.
Chen, F., Deng, Z., Deng, Y., Qiao, Z., Lan, L., Meng, Q., et al., 2017. Attributable risk of ambient PM10 on daily mortality and years of life lost in Chengdu, China. Sci. Total Environ. 581-582, 426–433.
Cheng, J., Xu, Z., Zhu, R., Wang, X., Jin, L., Song, J., et al., 2014. Impact of diurnal temperature range on human health: a systematic review. Int. J. Biometeorol. 58, 2011–2024.
Egondi, T., Kyobutungi, C., Rocklov, J., 2015. Temperature variation and heat wave and cold spell impacts on years of life lost among the urban poor population of Nairobi, Kenya. Int. J. Environ. Res. Public Health 12, 2735–2748.
Gardner, J.W., Sanborn, J.S., 1990. Years of potential life lost (YPLL)-what does it measure? Epidemiology 1, 322–329.
Gasparrini, A., Armstrong, B., Kenward, M.G., 2010. Distributed lag non-linear models. Stat. Med. 29, 2224–2234.
Gasparrini, A., Armstrong, B., Kenward, M.G., 2012. Multivariate meta-analysis for non-linear and other multi-parameter associations. Stat. Med. 31, 3821–3839.
Gasparrini, A., Guo, Y., Hashizume, M., Kinney, P.L., Petkova, E.P., Lavigne, E., et al., 2015a. Temporal variation in heat-mortality associations: a multicountry study. Environ. Health Perspect. 123, 1200–1207.
Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., et al., 2015b. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 386, 369–375.
Guo, Y., Barnett, A.G., Pan, X., Yu, W., Tong, S., 2011. The impact of temperature on mortality in Tianjin, China: a case-crossover design with a distributed lag nonlinear model. Environ. Health Perspect. 119, 1719–1725.
Guo, Y., Li, S., Tian, Z., Pan, X., Zhang, J., Williams, G., 2013a. The burden of air pollution on years of life lost in Beijing, China, 2004–08: retrospective regression analysis of daily deaths. BMJ 347, f7139.
Guo, Y., Li, S., Zhang, Y., Armstrong, B., Jaakkola, J.J., Tong, S., et al., 2013b. Extremely cold and hot temperatures increase the risk of ischaemic heart disease mortality: epidemiological evidence from China. Heart 99, 195–203.
Guo, Y., Gasparrini, A., Armstrong, B., Li, S., Tawatsupa, B., Tobias, A., et al., 2014. Global variation in the effects of ambient temperature on mortality: a systematic evaluation. Epidemiology 25, 781–789.

Guo, Y., Gasparrini, A., Armstrong, B.G., Tawatsupa, B., Tobias, A., Lavigne, E., et al., 2016. Temperature variability and mortality: a multi-country study. Environ. Health Perspect. 124, 1554–1559.
He, T., Yang, Z., Liu, T., Shen, Y., Fu, X., Qian, X., et al., 2016. Ambient air pollution and years of life lost in Ningbo, China. Sci Rep 6, 22485.
Huang, C., Barnett, A.G., Wang, X., Tong, S., 2012a. Effects of extreme temperatures on years of life lost for cardiovascular deaths: a time series study in Brisbane, Australia. Circ. Cardiovasc. Qual. Outcomes 5, 609–614.
Huang, C., Barnett, A.G., Wang, X., Tong, S., 2012b. The impact of temperature on years of life lost in Brisbane, Australia. Nat. Clim. Chang. 2, 265–270.
Huang, C., Barnett, A.G., Xu, Z., Chu, C., Wang, X., Turner, L.R., et al., 2013. Managing the health effects of temperature in response to climate change: challenges ahead. Environ. Health Perspect. 121, 415–419.
Huang, Z., Lin, H., Liu, Y., Zhou, M., Liu, T., Xiao, J., et al., 2015. Individual-level and community-level effect modifiers of the temperature-mortality relationship in 66 Chinese communities. BMJ Open 5, e009172.
Kravchenko, J., Abernethy, A.P., Fawzy, M., Lyerly, H.K., 2013. Minimization of heatwave morbidity and mortality. Am. J. Prev. Med. 44, 274–282.
Li, S., Baker, P.J., Jalaludin, B.B., Marks, G.B., Denison, L.S., Williams, G.M., 2014. Ambient temperature and lung function in children with asthma in Australia. Eur. Respir. J. 43, 1059–1066.
Li, J., Luo, S., Ding, X., Yang, J., Li, J., Liu, X., et al., 2016a. Influence of daily ambient temperature on mortality and years of life lost in Chongqing. Chin. J. Epidemiol. 37, 375–380.
Li, Q., Wang, H.J., Song, Y., Ma, J., Song, J.Y., Guo, Y., 2016b. Association between children's forced vital capacity and long-term exposure to local ambient temperature in China: a national cross-sectional survey. Sci. Total Environ. 557-558, 880–887.
Li, G., Huang, J., Xu, G., Pan, X., Qian, X., Xu, J., et al., 2017a. Temporal variation in associations between temperature and years of life lost in a southern China city with typical subtropical climate. Sci Rep 7, 4650.
Li, Y.H., Luo, S.Q., Lan, L., Jin, M.G., Yang, C., He, J.Y., et al., 2017b. Influence of extreme weather on years of life lost due to diabetes death in Chongqing and Harbin, China. Chin. J. Epidemiol. 38, 303–308.
Lin, H., Liu, T., Xiao, J., Zeng, W., Li, X., Guo, L., et al., 2016. Mortality burden of ambient fine particulate air pollution in six Chinese cities: results from the Pearl River Delta study. Environ. Int. 96, 91–97.
Lu, F., Zhou, L., Xu, Y., Zheng, T., Guo, Y., Wellenius, G.A., et al., 2015. Short-term effects of air pollution on daily mortality and years of life lost in Nanjing, China. Sci. Total Environ. 536, 123–129.
Ma, W., Chen, R., Kan, H., 2014. Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ. Res. 134, 127–133.
Ma, W., Wang, L., Lin, H., Liu, T., Zhang, Y., Rutherford, S., et al., 2015. The temperature-mortality relationship in China: an analysis from 66 Chinese communities. Environ. Res. 137, 72–77.
Naghavi, M., Wang, H., Lozano, R., Davis, A., Liang, X., Zhou, M., et al., 2015. Global, regional, and national age–sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the global burden of disease study 2013. Lancet 385, 117–171.
O'Neill, M.S., Zanobetti, A., Schwartz, J., 2003. Modifiers of the temperature and mortality association in seven US cities. Am. J. Epidemiol. 157, 1074–1082.
Penttinen, P., Timonen, K.L., Tiittanen, P., Mirme, A., Ruuskanen, J., Pekkanen, J., 2001. Number concentration and size of particles in urban air: effects on spirometric lung function in adult asthmatic subjects. Environ. Health Perspect. 109, 319–323.
Phung, D., Guo, Y., Nguyen, H.T., Rutherford, S., Baum, S., Chu, C., 2016a. High temperature and risk of hospitalizations, and effect modifying potential of socio-economic conditions: a multi-province study in the tropical Mekong Delta Region. Environ. Int. 92-93, 77–86.
Phung, D., Thai, P.K., Guo, Y., Morawska, L., Rutherford, S., Chu, C., 2016b. Ambient temperature and risk of cardiovascular hospitalization: an updated systematic review and meta-analysis. Sci. Total Environ. 550, 1084–1102.
Tian, Z., Li, S., Zhang, J., Jaakkola, J.J., Guo, Y., 2012. Ambient temperature and coronary heart disease mortality in Beijing, China: a time series study. Environ. Health 11, 56.
Vicedo-Cabrera, A.M., Forsberg, B., Tobias, A., Zanobetti, A., Schwartz, J., Armstrong, B., et al., 2016. Associations of inter- and intraday temperature change with mortality. Am. J. Epidemiol. 183, 286–293.
Wang, H., Naghavi, M., Allen, C., Barber, R.M., Bhutta, Z.A., Carter, A., et al., 2016. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the global burden of disease study 2015. Lancet 388, 1459–1544.
Wang, Q., Li, C., Guo, Y., Barnett, A.G., Tong, S., Phung, D., et al., 2017. Environmental ambient temperature and blood pressure in adults: a systematic review and meta-analysis. Sci. Total Environ. 575, 276–286.
Wu, S., Deng, F., Wang, X., Wei, H., Shima, M., Huang, J., et al., 2013. Association of lung function in a panel of young healthy adults with various chemical components of ambient fine particulate air pollution in Beijing, China. Atmos. Environ. 77, 873–884.
Wu, S., Deng, F., Hao, Y., Wang, X., Zheng, C., Lv, H., et al., 2014. Fine particulate matter, temperature, and lung function in healthy adults: findings from the HVNR study. Chemosphere 108, 168–174.
Xie, H., Yao, Z., Zhang, Y., Xu, Y., Xu, X., Liu, T., et al., 2013. Short-term effects of the 2008 cold spell on mortality in three subtropical cities in Guangdong Province, China. Environ. Health Perspect. 121, 210–216.
Yang, J., CQ, Ou, Ding, Y., Zhou, Y.X., Chen, P.Y., 2012. Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou. Environ. Health 11, 63.
Yang, J., CQ, Ou, Guo, Y., Li, L., Guo, C., Chen, P.Y., et al., 2015a. The burden of ambient temperature on years of life lost in Guangzhou, China. Sci Rep 5, 12250.
Yang, J., Yin, P., Zhou, M., CQ, Ou, Guo, Y., Gasparrini, A., et al., 2015b. Cardiovascular mortality risk attributable to ambient temperature in China. Heart 101, 1966–1972.
Yang, J., CQ, Ou, Song, Y.F., Li, L., Chen, P.Y., Liu, Q.Y., 2016a. Estimating years of life lost from cardiovascular mortality related to air pollution in Guangzhou, China. Sci. Total Environ. 573, 1566–1572.
Yang, J., Yin, P., Zhou, M., Ou, C.Q., Li, M., Li, J., et al., 2016b. The burden of stroke mortality attributable to cold and hot ambient temperatures: epidemiological evidence from China. Environ. Int. 92-93, 232–238.
Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., Tong, S., 2012. Ambient temperature and morbidity: a review of epidemiological evidence. Environ. Health Perspect. 120, 19–28.
Yu, W., Mengersen, K., Wang, X., Ye, X., Guo, Y., Pan, X., et al., 2012. Daily average temperature and mortality among the elderly: a meta-analysis and systematic review of epidemiological evidence. Int. J. Biometeorol. 56, 569–581.
Zeng, Q., Ni, Y., Jiang, G., Li, G., Pan, X., 2017. The short term burden of ambient particulate matters on non-accidental mortality and years of life lost: a ten-year multi-district study in Tianjin, China. Environ. Pollut. 220, 713–719.
Zhang, Y., Li, C., Feng, R., Zhu, Y., Wu, K., Tan, X., et al., 2016. The short-term effect of ambient temperature on mortality in Wuhan, China: a time-series study using a distributed lag non-linear model. Int. J. Environ. Res. Public Health 13, 722.
Zhang, Y., Peng, M., Yu, C., Zhang, L., 2017a. Burden of mortality and years of life lost due to ambient PM10 pollution in Wuhan, China. Environ. Pollut. 230, 1073–1080.
Zhang, Y., Yu, C., Bao, J., Li, X., 2017b. Impact of temperature on mortality in Hubei, China: a multi-county time series analysis. Sci Rep 7, 45093.
Zhang, Y., Yu, C., Bao, J., Li, X., 2017c. Impact of temperature variation on mortality: an observational study from 12 counties across Hubei Province in China. Sci. Total Environ. 587-588, 196–203.
Zhang, Y., Yu, C., Wang, L., 2017d. Temperature exposure during pregnancy and birth outcomes: an updated systematic review of epidemiological evidence. Environ. Pollut. 225, 700–712.
Zhang, Y., Yu, C., Yang, J., Zhang, L., Cui, F., 2017e. Diurnal temperature range in relation to daily mortality and years of life lost in Wuhan, China. Int. J. Environ. Res. Public Health 14, 891.
Zhao, Q., Zhang, Y., Zhang, W., Li, S., Chen, G., Wu, Y., et al., 2017. Ambient temperature and emergency department visits: time-series analysis in 12 Chinese cities. Environ. Pollut. 224, 310–316.
Zhou, M.G., Wang, L.J., Liu, T., Zhang, Y.H., Lin, H.L., Luo, Y., et al., 2014. Health impact of the 2008 cold spell on mortality in subtropical China: the climate and health impact national assessment study (CHINAs). Environ. Health 13, 60.